11 Selecting Watershed and Instream Models

One common objective of water quality modeling studies is to be able to predict the impact of different point and nonpoint source loading scenarios on surface water bodies. The historic reliance on the use of design flows for developing permit limits and for evaluating attainment of water quality standards has done nothing to prepare TMDL practitioners for developing TMDLs on waterbodies that receive inputs from both point sources (steady, continuous loads) and nonpoint sources (unsteady, discontinuous loads). The episodic discharges from the nonpoint sources, occurring as a result of rain or melting snow, enter streams whose assimulative capacities (generally approximated as dilution ratios) are not well represented by the design flows (7Q10 or 4B3) traditionally used for setting permit limits for point sources. While determining the allowable load allocation from the nonpoint sources based on a design flow would be environmentally protective, it probably would be unfair to the point source dischargers and impossible to attain under many conditions. The fact that releases from both point sources and nonpoint sources must be combined for TMDL purposes is totally logical. Fortunately, we can make the process of developing TMDLs easier through intellegent use of today's powerful desktop computers, Geographic Information Systems, environmental databases, and watershed models supported with graphical interfaces that render them faster and easier to use.

The easiest way to envision the necessary integration of loads from point and nonpoint sources is to consider what it would be like if you could continually measure the concentrations of the pollutants of concern in the watershed. Assume that you could locate sensors at appropriate locations and collect data on chemical concentration, stream volume flow, temperature, pH, and other properties continuously (or even daily) for several years, you could develop a database that you could use to evaluate the health of the waterbody or of the watershed. With such a database, you could develop statistical descriptions of the distributions of pollutant concentrations that have resulted from the combination of PS and NPS loadings within the watershed. If you were to continue this monitoring effort for a couple decades, you could then evaluate whether or not water quality criteria (i.e., chemical concentrations) were being exceeded more frequently than specified in the State's water quality standards.

As it is unlikely that you will have either the time or money to develop such a data record for many watersheds, the next best way to generate the data needed to evaluate attainment of water quality standards is to model the watershed. By running a continuous simulation model, you can synthesize a database that is analogous to that described above. In this exercise you would simulate daily values of stream volume flow, pollutant loadings, pollutant concentrations, etc. for an appropriate period of record. The computer output from this watershed modeling study would look very much like the database from the monitoring study and the data would be subjected to the same statistical tests.

Loadings from point sources are based on resources such as the permitted releases of chemicals from municipal and industrial facilities (e.g, EPA's Permit Compliance System database) or from monitoring data collected at these facilities (e.g., Discharge Monitoring Reports). Loadings from non-point sources are estimated by the watershed models; the loads depend on factors such as land use, vegetation cover, and meteorological conditions. The resulting pollutant concentrations are estimated by dividing the daily loadings (total of loads from both PS and NPS) by the model generated daily stream flow. If in-stream concentrations exceed criteria, loads are reduced until standards are attained.

Water Quality Modeling Based on Hydrologic Principles

A continuous simulation model was considered to be critical for a realistic representation of watershed processes. Continuous simulation models combine daily (or other time-step) measurements or synthesized estimates of effluent flows and loads, wet-weather source concentrations and loads, and receiving water flows to calculate receiving water concentrations. A deterministic model is applied to time series of these variables to predict resulting concentrations in chronological order, with the same time sequence as the input variables. This enables a frequency analysis of concentrations at a given point of interest, as will be explained more fully below.

In natural systems, flows typically exhibit correlation in time (serial correlation), so that low flow days tend to follow other low flow days, and high flow days follow high flow days. Precipitation-driven episodic loads often exhibit cross-correlation (correlation between different variables) with receiving water flow, as the same precipitation that generates the load may also increase flow throughout the watershed. Both serial and cross-correlation can have important implications for predicting water quality impacts. For instance, if episodic loads are most likely to occur when flow in the receiving water is high, an adverse impact on water quality is much less likely than if the loads occur when flow in the receiving water is low.

A continuous simulation approach automatically takes into account the serial correlation present in flows and other variables, as well as cross-correlations between measured variables, because real data are used. This is potentially the most powerful method available for accurate prediction of the frequency of receiving water concentrations, but it does have disadvantages. Notably, the method is very data intensive and may require observations over many years to accurately evaluate the frequency of occurrence of water quality excursions. Long time series of monitoring data for wet-weather loads will generally not be available and may have to be simulated from precipitation records using rainfall-runoff models. Simulating data introduces uncertainty; indeed, if good observations of time series of more than one input parameter are lacking it may be preferable to use a statistical simulation approach (such as the Monte Carlo method described below) which allows a direct analysis of the effects of input uncertainty on model predictions.

How Do I Choose Which Model to Use?

There are many factors to consider when selecting the model. The question “Is this the best model?” may be answered by the question “For what purpose?”. What data do you have to represent the watershed that you are modeling? What processes in the watershed are important to your study? What are the appropriate scales of resolution, both space (distance) and time? What are the uncertainties associated with the quality of the data? What are the uncertainties associated with the effectiveness of the proposed controls? If the results (model output) of the watershed modeling study are going to be used as (part of the) input to a lake or reservoir model of nutrient eutrophication, is the eutrophication model of the same temporal scale? That is, does the eutrophication model require a seasonal or annual nutrient input or does it simulate processes that account for daily fluctuations in nutrient loads?

At the risk of oversimplifying a very complex issue, the developers of BASINS wish to provide some general guidance. PLOAD, SWAT and HSPF are spatially distributed, lumped parameter models. They may be used to analyze watersheds and river basins by subdividing the area into homogenous parts.

PLOAD is a simple watershed model that computes nonpoint source loads from different subwatersheds and landuses based on annual precipitation, landuses and BMP’s. Successful linking of the model to existing BASINS data and user supplied data makes the model useful in estimating nonpoint source loads, relative contributions and load reduction by BMP’s. PLOAD requires watershed boundary, landuse, best management practices (BMPs), point sources and annual precipitation data to compute pollutant loads. Additionally PLOAD requires event mean concentrations (EMCs) and/or loads per acre tables for different land use types. *Use PLOAD when you want estimates of seasonal or annual loadings to feed simple eutrophication models; or where there is great uncertainty in effectiveness of controls and adjustments to the TMDL may be expected after post-implementation monitoring.*

HSPF version 12 includes a simplified snow melt algorithm (i.e., degree-day approach), the ability to model land-to-land transfers, high water tables and surface ponding (wetlands), and the addition of new BMP and Reporting modules. The new SNOW module requires only precipitation and air temperature time series, while producing essentially the same output as the current module which requires five additional meteorological time series (evaporation, wind speed, solar radiation, dew point, and cloud cover). *Use HSPF where the BASINS holdings provide hourly meteorological data from a location on or near your watershed. Also, you may use the WDMUtil tool to develop your own file of hourly meteorological data for a more appropriate meterological station than is included in the BASINS holdings. If you do not have a USGS gage station on your watershed (to calibrate the hydrology) you can used the paired watershed approach of calibrating HSPF on a nearby watershed of similar characteristics and then applying the calibrated model to your watershed for the purpose of developing the TMDL.*

SWAT simulates hydrology, pesticide and nutrient cycling, bacteria transport, erosion and sediment transport . SWAT is ideally suited to predict effects of land use management (such as climate and vegetative changes, agricultural practices, reservoir management, groundwater withdrawals, water transfer) on water, sediment, and chemical yields from river basins. SWAT uses a daily time step for simulations running from 1 to 100 years; (HSPF, as implemented in BASINS, uses an hourly time step.) We anticipate that SWAT will meet many modeling needs for situations where TMDLs need to be developed for watersheds dominated by lands in agricultural operations. *Use SWAT where there is no nearby meterological station with hourly data and/or where there is no nearby gaged watershed.*

QUAL2E is a steady-state,one-dimensional receiving water quality model. A QUAL2E simulation includes point source and Reach File 1 data from BASINS View, as well as any user-supplied nonpoint source data. Some of the BASINS data are tailored, with as few changes as possible, to allow the input file to fulfill QUAL2E requirements. Hydraulic structures or dams are not retrieved by the GIS to support the configuration of the stream system selected for simulation. *Use QUAL2E where you are concerned with a DO endpoint in an effluent dominated system where you can justify the use of low flow steady state assumptions.*

The BASINS system also enables the user to view output from these models in a spatial context. Generation and analysis of model simulation scenarios (GenScn), was developed to create simulation scenarios, analyze results of the scenarios, and compare scenarios. GenScn provides an interactive framework for analysis built around HSPF for simulating the hydrologic and associated water quality processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. GenScn also supports SWAT output time-series post processing. The GenScn graphical user interface (GUI) uses standard Windows 95/98/NT components. The strengths of this component have been added to BASINS and provides most of the post processing and display features.The *GenScn Visualization* tool allows the user to select a classification scheme for visually displaying various flow and pollutant levels in each reach modeled.

11.1 QUAL2E

Purpose

The *QUAL2E* model allows users to simulate the fate and transport of water quality constituents in streams under a given flow condition.

Application

QUAL2E is a steady-state,one-dimensional receiving water quality model. Data processing and preparation of an input file for *QUAL2E* is automated within the BASINS system. A *QUAL2E* simulation includes point source and reach data from BASINS View, as well as any user-supplied nonpoint source data. Some of the BASINS data are tailored, with as few changes as possible, to allow the input file to fulfill *QUAL2E* requirements. QUAL2E Windows Interface User's Manual (USEPA, 1995) and The Enhanced Stream Water Quality Models *QUAL2E* and *QUAL2E-UNCAS*: Documentation and User Manual (Brown and Barnwell, 1987) provide further details. Hydraulic structures or dams are not retrieved by the GIS to support the configuration of the stream system selected for simulation.

Key Procedures:

- Activate the Reach File theme
- Select the reaches you want to simulate using *QUAL2E*
- Select *QUAL2E* under the Models menu
- Select a year for point source discharge
- Select conservative and nonconservative water quality constituents
- Import QUALINP.RUN using Run under the Import menu in *QUAL2E*
- View and edit data
- Click on Run to execute *QUAL2E*

BASINS contains an extension that allows the user to run QUAL2E directly from the BASINS user interface. See the QUAL2E Extension User's Manual for instructions on using this extension.

11.2 HSPF

Hydrological Simulation Program Fortran (HSPF), version 12, is accessed through the *WinHSPF* interface. HSPF is a watershed model that simulates nonpoint source runoff and pollutant loadings for a watershed, combines these with point source contributions, and performs flow and water quality routing in reaches. In earlier versions of BASINS, the interface to HSPF was known as the Nonpoint Source Model (NPSM). The look and feel of WinHSPF is patterned after NPSM to ease the user's transition to this more powerful software. All features of HSPF are available through WinHSPF. It fully supports the MASS-LINK, SCHEMATIC and SPECIAL ACTIONS blocks of the UCI File. This interface also directly reads HSPF UCI file. See the WinHSPF User's Manual for instructions on using WinHSPF. The HSPF User's Manual is also available for reference.

WinHSPF can be run on a single watershed or a system of multiple hydrologically connected subwatersheds that have been delineated using the BASINS *Watershed Delineation* tool. The model requires land use data, reach data, meteorological data, and information on the pollutants of concern in the watershed and the reaches. WinHSPF is designed to interact with the BASINS utilities and data sets to facilitate the extraction of appropriate information and the preparation of model input files. The reach network is automatically developed based on the subwatershed delineations. Users can modify and adapt input files to site-specific conditions through the use of *WinHSPF* and supporting information provided by the BASINS utilities and reporting functions, as well as locally derived data sources. WinHSPF works with postprocessing tools to facilitate display and interpretation of output data.

BASINS contains an extension that allows the user to open WinHSPF directly from the BASINS user interface. See the HSPF Extension User's Manual for instructions on using this extension.

HSPF requires Watershed Data Management (WDM) files, which contain input and output timeseries data, in order to run. *WDMUtil* is a utility program for managing such files. See the WDMUtil User's Manual for instructions on using WDMUtil. BASINS contains an extension that allows the user to open WDMUtil directly from the BASINS user interface. See the WDMUtil Extension User's Manual for instructions on using this extension.

11.3 SWAT

The Soil and Water Assessment Tool (SWAT) model, version 2000, is a river basin, or watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields on complex watersheds with varying soils, land use, and management conditions. The model combines these with point source contributions, and performs flow and water quality routing in stream reaches. The model is physically based and computationally efficient, uses readily available inputs and enables users to study long-term impacts.

The BASINS SWAT Extension is designed to interact with the BASINS utilities and data sets to set up and modify the SWAT model input files as well as facilitate the calibration of the model based on site-specific conditions and data sources. SWAT can be run on a single watershed or a system of multiple hydrologically connected subwatersheds that have been delineated using the BASINS Watershed Delineation tool. The user can set up SWAT simulations using the data provided with BASINS (land use, soils, reach data, meteorological, pollutants, etc. data) and/or introduce custom data. BASINS SWAT Extension works with postprocessing tools to facilitate display and interpretation of output data.

See the SWAT Extension User's Manual for instructions on using the BASINS SWAT Extension interface. The SWAT 2000 User's Manual is also available for reference.

11.4 PLOAD

PLOAD is a simplified GIS based model developed by CH2M HILL for calculating pollutant loads from watersheds. PLOAD estimates nonpoint loads (NPS) of pollution on an annual average basis, for any user-specified pollutant. The user may calculate the NPS loads using either the export coefficient or the EPA's Simple Method approach. Optionally, best management practices (BMPs), which serve to reduce NPS loads, and point source loads may also be included in computing total watershed loads. Finally, there are several product alternatives that may be specified to show the NPS pollution results as maps and tabular lists, and to compare multiple sessions.

The PLOAD application requires pre-processed GIS and tabular input data as listed below:

- GIS landuse data
- GIS watershed data
- GIS BMP site and area data (optional)
- Pollutant loading rate data tables
- Impervious terrain factor data tables
- Pollutant reduction BMP data tables (optional)
- Point source facility locations and loads (optional)

PLOAD was designed to be generic so that it can be applied as a screening tool in a wide range of applications including NPDES stormwater permitting, watershed management, or reservoir protection projects. Its organization and structure of the application facilitates modification and customization. It was designed to be an analytical tool for end users. PLOAD uses the menu-driven ArcView desktop GIS. Custom scripts were written with ArcView's Avenue scripting language. See the PLOAD User's Manual for instructions on using PLOAD.